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Global Positional Proportional Fairness Based on Spectrum Aggregation in Cognitive Radio

Cong Yin*[1], Xuezhi Tan[2], Lin Ma[3], Guanyuan Feng[4]

[1]Communication Research Center, Harbin Institute of Technology, Harbin, China

[2]Communication Research Center, Harbin Institute of Technology, Harbin, China

[3]Communication Research Center, Harbin Institute of Technology, Harbin, China

[4]Communication Research Center, Harbin Institute of Technology, Harbin, China

*[1]11B305006@hit.edu.cn; [2]tanxz1957@hit.edu.cn; [3]malin@hit.edu.cn; [4]14B305003@hit.edu.cn

Abstract

In cognitive radio system, when spectrum aggregation technology is involved to support numerous data transmission, it is still a problem that band resources scheduling is unfairness among secondary users. A global positional proportional fairness scheduling algorithm is investigated based on spectrum aggregation to clarify the problem. This paper focuses on the relationship between spectrum aggregation and fairness scheduling of secondary users. Bandwidth fairness can be improved by considering the positional parameters if secondary users are at disadvantage locations which make the band resources restricted. Simulation results show that the proposed scheduling algorithm takes advantages of bandwidth fairness comparing with the traditional scheduling algorithms without positional parameters. Meanwhile it presents that the proposed fairness scheduling algorithm sacrifice bandwidth jitter index to make sure of fairness among secondary users.

Keywords

Cognitive Radio; Spectrum Aggregation; Proportional Fairness Scheduling Algorithm

Introduction

Wireless communication systems become more intelligent and powerful which is relying on technologies of broadband. All kinds of requirements such as video conference and network stream media can be satisfied by WLAN, 3G and 4G. Large bandwidth services will be provided for entertainment and business activities at the moment [Iwamura et al, 2010] [Shen et al, 2012]. However, statistical data supported by Federal Communications Commission (FCC) present that contiguous large spectrum available scarcely exists. Therefore spectrum aggregation (SA) has been proposed by QinetiQ Corporation of British to make non-contiguous spectrum efficient for broadband service in 2006[Guillermo et al, 2011] [Pedersen et al, 2011]. Spectrum aggregation has been applied in LTE-A to support the transmission of considerable amount of information. And operation principles of SA correspond to the peculiarity of cognitive radio system, which is non-interference between primary users (PUs) and secondary users (SUs). Thus how to aggregate non-contiguous spectrum in cognitive radio system is essential for SUs [Li et al, 2010]. Furthermore, how to schedule resource fairly based on SA is worth considering [Zhou et al, 2010] [Shi et al, 2013].

Classic fairness scheduling algorithms include: Max C/I, Round Robin (RR), Proportional Fairness (PF). PF has been proved to utilize spectrum efficiently while allocate resource to users fairly. PF has been already researched extensively and deeply. In [Attar et al, 2010] a time mechanism fairness scheduling algorithm is advised to allow SUs accessing to primary users' network in order to utilize resources rationally. However, the bandwidth and throughput fairness are not mentioned to describe data rate of SUs. In [Zhou et al, 2011] a global proportional fairness scheduling algorithm is proposed based on multiple base stations. With the purpose of optimization system throughput, this algorithm makes use of utility function to allocate resource to users efficiently in the whole networks. Nevertheless, positional parameters are not considered in the model and unfairness ascribe to positions cannot be explained. Some papers give a new method of scheduling resources in the OFDM scenario. One paper brings hierarchical modulation in PF scheduling to increase throughput of system [Ren et al, 2013]. A PF scheduling is presented in cognitive radio system with spectrum underlay. Therefore SUs can acquire larger

bandwidth when spectrum resource is limited [Wang et al, 2010]. The length of queue is modified by delay control of PF scheduling so that the data rate of users can be obtained by this feedback [Jeon et al, 2012]. These references above have focused on bandwidth or throughput improvement by different methods in different scenarios. However unfairness problem caused by disadvantage positions is not mentioned. Therefore this paper establishes a PF scheduling model based on SA with disadvantage positional conditions of SUs.

Firstly a global proportional fairness (GPF) scheduling method based on SA is suggested to demonstrate bandwidth fairness of SUs when SA is involved [Yin et al, 2014]. Then unfairness problem due to disadvantage positions of SUs will be presented. Disadvantage positions mean that geographical distribution of SUs cannot be covered by the whole bandwidth of the base station. In other words, only parts of frequency band may cover the locations of SUs so that their spectrum resource available for aggregation is restricted and they cannot utilize the whole system resource sufficiently. With the purpose of solving the unfairness problem above, a global positional proportional fairness (GPPF) scheduling algorithm based on SA is advised. And at last the simulation results of Jain fairness index, bandwidth jitter index and other factors are presented to illustrate GPPF scheduling algorithm superiority.

System Model

Fig.1 demonstrates a classic model of cognitive radio system with spectrum aggregation. PUs and SUs' positions are distributed random below the base station and both covered by the frequency band.

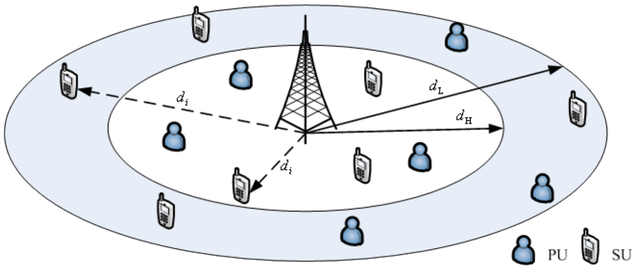

FIG. 1 COVERAGE MODEL OF A BASE STATION

In Fig.1 d_L is the farthest edge that the lowest frequency f_L of the base station can reach and d_H is the farthest edge that the highest frequency f_H of the base station can reach. d_i is the position of SU i . The area between d_L and d_H can be defined as "shadow". If all SUs' positions are out of the shadow, they can fully occupy the system resource for aggregating spectrum. And their bandwidth fairness can be evaluated by GPF. If some SUs' positions are in the shadow, they cannot utilize the whole system resource sufficiently for spectrum aggregation. Their bandwidth will be restricted and fairness among all SUs will be affected which can be evaluated by GPPF.

A Cost-231 Hata propagation distance formulation is cited to show the relations between frequency bands and distances. It is given as follow.

$$\begin{aligned} Loss(\mathrm{dB}) = {} & C_1 + C_2 \log_{10} f_i - C_3 \log_{10} H_{\mathrm{te}} - \alpha(H_{\mathrm{re}}) \\ & + (C_4 - C_5 \log_{10} H_{\mathrm{te}}) \log_{10} d_i + C_{\mathrm{cell}} + C_{\mathrm{terrain}} + C_{\mathrm{M}} \end{aligned} \tag{1}$$

Here $C_1, C_2, C_3, C_4, C_5, C_{\mathrm{cell}}, C_{\mathrm{terrain}}, C_{\mathrm{M}}$ are modified factors. In the background of this paper, $Loss(\mathrm{dB})$ is the same value because of the same base station. All parameters in (1) are constant except d_i and f_i. Different frequencies correspond to different propagation distances. So (2) can be obtained from (1) as follow if $f_i = f_L, f_H$ respectively.

$$\mathrm{A} \cdot \log_{10} \frac{f_L}{f_H} = \mathrm{B} \cdot \log_{10} \frac{d_H}{d_L} \tag{2}$$

$$\begin{aligned} &\mathrm{A} = C_2 \\ &\mathrm{B} = C_4 - C_5 \log_{10} H_{\mathrm{te}} \end{aligned} \tag{3}$$

To simplify the calculations, assume A equals B. And (4) is acquired.

$$\frac{f_{\mathrm{L}}}{f_{\mathrm{H}}} = \frac{d_{\mathrm{H}}}{d_{\mathrm{L}}} \tag{4}$$

From (4), a relationship of d_i and f_i is presented. According to the protocol of IEEE 802.22, the whole TV broadcast bands are available for SUs from 54MHz to 862MHz. In this paper, the UHF band of TV which is defined from 300MHz to 862MHz is chosen for simulations. Then if d_{H} is assumed 10km, d_{L} can be calculated 28.7km.

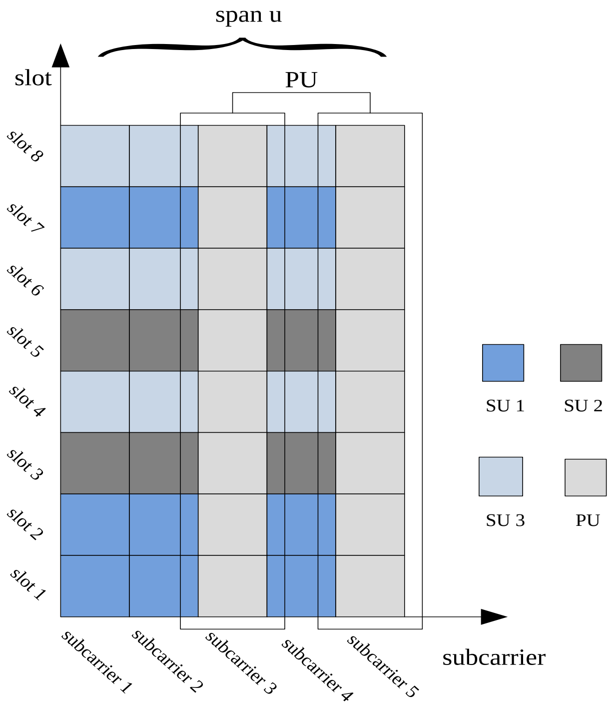

FIG. 2 A MODEL OF RESOURCE SCHEDULING BASED ON SEPCTRUM AGGREGATION

Resource Fairness Scheduling Based on SA

Fig. 2 gives a model of resource scheduling based on SA in span u. There are three SUs for instance in this model. In each slot they are scheduled and acquire resource blocks obeying global proportional fairness (GPF) rules as (5) and (6). Here the length of remaining data of SU i is $L_i(t)$ at moment t after one slot transmission.

$$\hat{i} = \arg\max_i \frac{b_i(t,u)}{B_i(t,u)} \cdot L_i(t) \tag{5}$$

$$\begin{aligned} & b_i(t,u) = \sum_{n=1}^{N} x_{n,i}^u(t) \cdot cc_{n,i}^u(t) \\ s.t. \quad & x_{n,i}^u(t) = \begin{cases} 0 & \text{PU} \\ 1 & \text{SU} \end{cases} \\ & b_i(t,u) \le S \\ & u \in U \qquad i = 1,2,\ldots,K \end{aligned} \tag{6}$$

$\hat{i}$ is the SU who is scheduled at moment t. $b_i(t,u)$ is bandwidth of SU i at slot t in span u after aggregating subcarriers. $cc_{n,i}^u(t)$ is bandwidth of subcarrier n in span u at slot t. If subcarrier n is occupied by PU, $x_{n,i}^u(t)$ equals 0, which means that SU i cannot use it. If subcarrier n is idle, $x_{n,i}^u(t)$ equals 1, which means that SU i can use it. S is width of a span and there are totally U spans according to the bandwidth of the base station. SU i ignores some resource blocks which are occupied by PUs and continues to utilize the rest ones for SA using (6).

$$B_i(t,u) = \frac{1}{T} \sum_{\tau=t-T}^{\tau=t-1} b_i(\tau,u) \tag{7}$$

$$B_i\left(t+1,u\right)=\left(1-\frac{1}{T}\right)B_i\left(t,u\right)+\frac{1}{T}b_i\left(t,u\right) \tag{8}$$

$B_i\left(t,u\right)$ is average bandwidth of SU i before the moment t. T is time window. $B_i\left(t+1,u\right)$ is update function of average bandwidth.

In the Fig.2, the global proportional fairness rules can be demonstrated. Three colour blocks represent resources that three SUs can utilize. In slot1 and slot2, SU1 can occupy subcarrier1, subcarrier2 and subcarrier4 and cannot use subcarrier3 and subcarrier5 due to PU arriving. In each slot, system calculates the values of SUs' priority according to (5) and schedule one SU whose priority is the highest. The scheduling results of each slot can be seen from Fig.2, which are SU1, SU1, SU2, SU3, SU2, SU3, SU1, and SU3.

Global Positional Proportional Fairness Scheduling Based on SA

In this section, an algorithm with positional parameters is proposed based on SA which is global positional proportional fairness scheduling (GPPF). The key problem of the GPPF scheduling algorithm is the priority of SUs. One SU is scheduled in each slot and the priority of every SU determines who will be scheduled next moment. So the priority affects fairness of algorithm directly. If the SUs' places are out of the "shadow", their priorities $Q_r\left(t\right)$ can be obtained from (9). If their positions are in the "shadow", their priorities $\overset{\square}{Q}_k\left(t\right)$ will be acquired from (10).

$$Q_r\left(t\right)=\frac{b_r\left(t,u\right)}{B_r\left(t,u\right)}\cdot L_r\left(t\right) \qquad d_r\le d_{\mathrm{H}}, r\in i \tag{9}$$

$$\overset{\square}{Q}_k\left(t\right)=\beta\cdot\frac{b_k\left(t,u\right)}{B_k\left(t,u\right)}\cdot L_k\left(t\right) \qquad d_{\mathrm{L}}>d_k>d_{\mathrm{H}}, k\in i \tag{10}$$

$$\beta=\frac{d_{\mathrm{L}}-d_{\mathrm{H}}}{d_{\mathrm{L}}-d_k} \tag{11}$$

Here β is weighted factor of the SU who is in the "shadow". In Fig.3 the SU's position is located at d_k which is between d_{H} and d_{L}. If the SU is closer to d_{L}, the weighted factor β gets larger according to (11). Consequently, the SU whose position is in"shadow" will be compensated for its finite band resources by higher priority from weighted factor β.

All the SUs have different priories at the same time. All the priorities of SUs should be compared with each other to conclude that who has the highest priority for scheduling. $Q_r\left(t\right)$ and $\overset{\square}{Q}_k\left(t\right)$ represent the priorities of SUs whose positions are out of "shadow" and in "shadow" respectively. One SU will be scheduled wherever it is after comparison by (12). $\hat{i}$ is the SU who is scheduled at moment t.

$$\begin{gathered}\hat{i}=\arg\max_{r,k\in i}\left\{Q_r\left(t\right),\overset{\square}{Q}_k\left(t\right)\right\}\\ i=1,2\ldots K\end{gathered} \tag{12}$$

Here is an assumption as follows. If the band resources are allocated unfairly to the SUs whose positions are in the shadow for a while, they will move out of the shadow towards to the base station. In other words, they abandon the original positions ascribe to unsatisfied bandwidth and choose new positions with full coverage of signals so as to acquire better bandwidth. After a long time, all the SUs will move out of shadow and their positions will be chose within the scope of 10km, closer to the base station. This process can be defined as "Extension". Fig.4 displays the extension process.

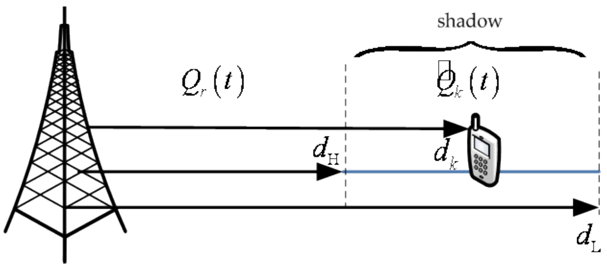

FIG. 3 POSITIONAL PARAMETERS IN COVERAGE MODEL OF A BASE STATION

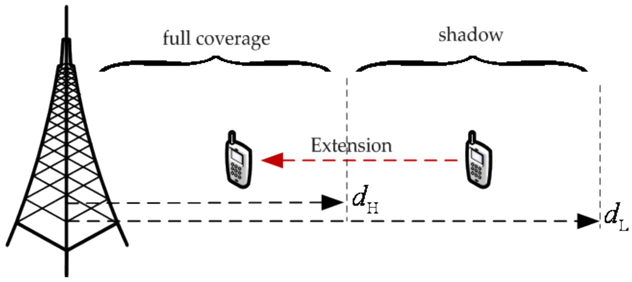

FIG. 4 EXTENSION PROCESS OF SECONDARY USERS

Measurement of Global Positional Proportional Fairness

Jain index is a typical method for measuring fairness of system [Shi et al, 2013]. Here the Jain index value is adopted for all the SUs who are covered by the base station. Therefore the fairness index of GPPF will be obtained as follows.

$$Jain(t)=\frac{\left[\sum_{i=1}^{K}B_i(t+1,u)\right]^2}{K\sum_{i=1}^{K}\left[B_i(t+1,u)\right]^2} \tag{13}$$

Here $0\le Jain(t)\le 1$, at the moment t a large value of $Jain(t)$ represents fairer resource allocation than a small value of $Jain(t)$ from the system perspective.

Bandwidth jitter index value can measure the bandwidth variation of a SU and it reflects the QoS of SU directly. If the value of jitter index is large, it represents that bandwidth of the SU varies a lot during transmission. The smaller jitter index value is, the better SU's service will be.

$$Jit_i(\phi)=\frac{1}{\phi}\sum_{t=1}^{\phi}\left(\frac{b_i(t,u)-B_i(t,u)}{B_i(t,u)}\right)^2 \tag{14}$$

Here ϕ is statistical time. $Jit_i(\phi)$ is the bandwidth jitter index of SU i . $Jit_i(\phi)$ will be calculated more accurate by a large value of ϕ . From (14) each SU's jitter index will be presented that can be seen as a performance of GPPF.

Simulation Results and Discussion

In this section, simulation results about bandwidth, Jain fairness index and jitter index are demonstrated. Here a slot is assumed 0.5ms. The length of data queue of a SU equals the data of a song about 4MB. According to the protocol of IEEE 802.22, the UHF band of TV is chosen for simulations in this paper, which is defined from 300MHz to 862MHz. d_H is assumed 10km. d_L can be calculated 28.7km. Then, four fairness scheduling algorithms are compared which are mentioned above. They are global proportional fairness scheduling (GPF), global positional proportional fairness scheduling (GPPF), GPF-Extension and positional proportional fairness scheduling in shadow (PPF-Shadow).

In Fig.5 four scheduling algorithms are shown about Jain fairness index. The number of SUs is 30 and the length of data queue of a SU approximately equals to 30000kbits. All 30 SUs positions are distributed from 1km to 28.7km.GPF-Extension means all SUs move out of shadow(10km-28.7km), and their band resources for aggregation are not restricted, so its Jain fairness index is the best of all. GPPF and PPF-Shadow both contain weighted factor β . This weighted factor can improve the priority of SUs and compensate for limited resources ascribe to the disadvantage of geographical positions. Therefore their Jain fairness indexes rank in the middle. GPF is ordinary scheduling algorithm for aggregate spectrum. The SUs in the shadow cannot be covered by the whole band of base station and aggregate the spectrum restrictedly. The bandwidths of SUs after aggregation are different and unfair. So Jain fairness index is the worst. The algorithm of GPPF scheduling is suitable for coverage of the whole band, from 1km to 28.7km. However, PPF-Shadow is only suitable for shadow, from 10km to 28.7km. From the

perspective of fairness for all SUs under the base station, GPPF should be better than PPF-Shadow. The simulation results of GPPF and PPF-Shadow have proved this point.

Fig.6 demonstrates bandwidths of 30 SUs of four algorithms. GPF-Extension presents all SUs move out of shadow and their bandwidths aggregated are not restricted. Thus each SU can aggregate enough bandwidth and the fairness of SUs can be confirmed easily. Not considering geographical factor, GPF algorithm results in different bandwidths of 30 SUs. If SUs' positions are full covered by base station signal, their bandwidths are aggregated sufficiently. If SUs' positions are further from the base station and even in the shadow, their bandwidths become narrow. So the bandwidths are diminishing if GPF algorithm is adopted and its fairness is the worst. Due to the weighted factor β, GPPF algorithm makes SUs who are furthest scheduled more than others. This method balances all SUs' bandwidths after aggregation and makes almost the same bandwidths even though they are not very wide.

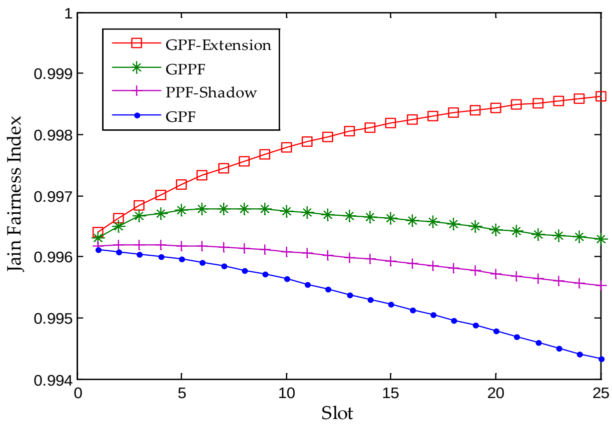

FIG. 5 JAIN FAIRNESS INDEX COMPARISON

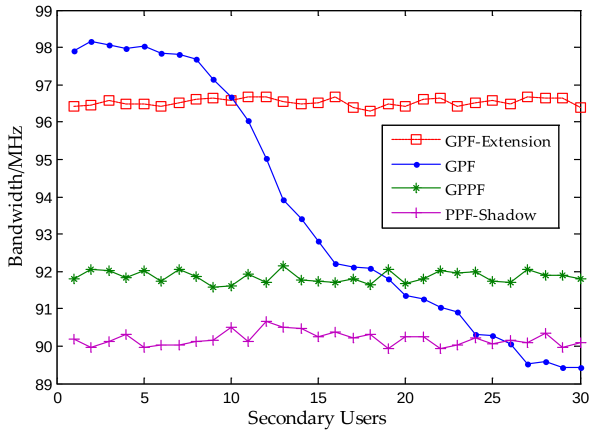

FIG. 6 BANDWIDTH COMPARISON OF FOUR ALGORITHMS

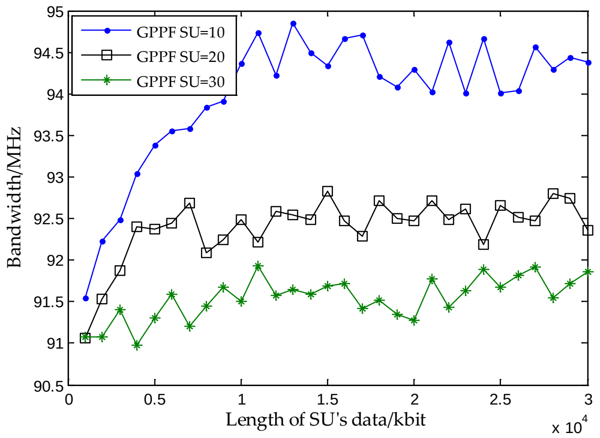

FIG. 7 BANDWIDTH OF GPPF WITH LENGTH OF DATA

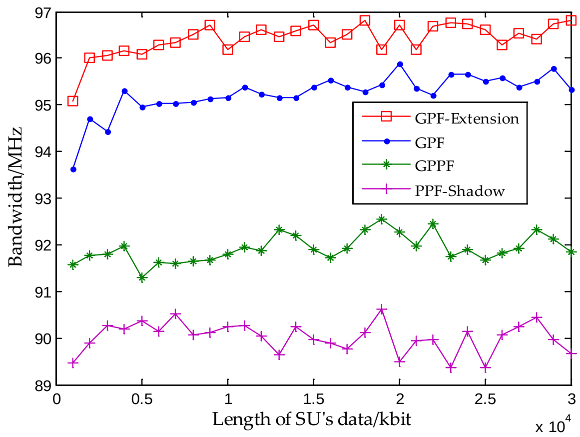

FIG. 8 BANDWIDTH COMPARISON WITH LENGTH OF DATA

Fig.7 depicts bandwidth is affected by length of data with different number of SUs if GPPF is adopted. The more the SUs are, the less the bandwidth is. When the length of data exceeds 10000kbit, bandwidths are stable at 94.5MHz, 92.5MHz and 91.5MHz when the number of SUs is 10, 20, and 30.

In Fig.8 it can be seen that the relationship between bandwidths and length of SUs' data. Here bandwidths are average values of 30 SUs. Four algorithms are stable at about 96MHz, 95MHz, 92MHz and 90MHz respectively as the length of data increasing. Due to the geographical positions, GPF algorithm makes 30 SUs acquire different bandwidths just like the simulation of GPF in Fig.6. However, the mean value of bandwidths is not small like the results of GPF in Fig.8. Rest of three algorithms can be corresponded to the values in Fig.6.

Bandwidth jitter index reflects stability of the algorithm and it shows the QoS of SUs. Fig.9 display bandwidth jitter index of GPF affected by positions from 1km to 28km. In the scope of 20km, the jitter index varies not too much, but beyond 20km the jitter index leaps a lot. Hidden behind the appearance are restricted band resources. In 20km, the coverage of band is sufficient, so the available band for aggregation is plenty. Beyond 20km, band resources are

limited due to partial coverage of signal. Therefore bandwidths of SUs vary a lot and jitter index value is large. It also can be confirmed that bandwidth jitter index increase if SUs' number enhance. However, at the furthest places from 20km to 28km, jitter index reaches its ceiling and will not increase sharply along with the growth of SUs' number.

Fig.10 shows that bandwidth jitter index of GPPF are divided to three stages by positions. From 1km to 10km, jitter index is the lowest because of unrestricted band resources for aggregation. Bandwidths of each SU do not alter too much. If SUs' positions are at the scope of 11km to 20km, their available band resources for aggregation become decrease. Bandwidths of each SU will alter much more than before. At the farthest positions from 21km to 28km, band resources are not sufficient for SUs to aggregate. Therefore each SU's bandwidth will change frequently during transmission. With the help of weighted factor, GPPF provide more scheduling opportunities to the SUs who are in shadow, farther from the base station. In order to make SUs more fairness, the proposed GPPF sacrifice jitter index of SUs. That is sacrificing QoS for fairness. The jitter index of GPF is lower than the jitter index of GPPF. This can be proved from Fig.9 and Fig.10.

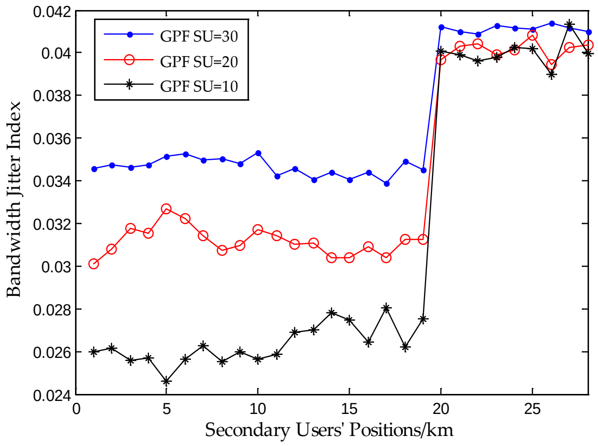

FIG. 9 BANDWIDTH JITTER INDEX OF GPF AFFECTED BY POSITIONS

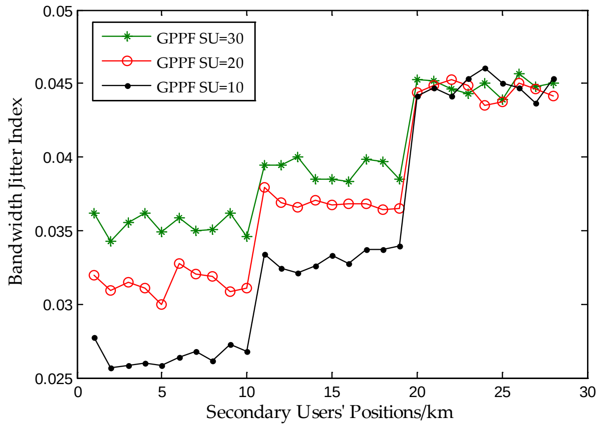

FIG. 10 BANDWIDTH JITTER INDEX OF GPPF AFFECTED BY POSITIONS

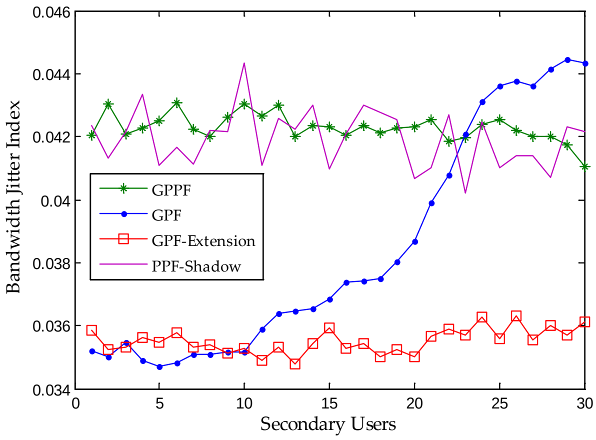

FIG. 11 BANDWIDTH JITTER INDEX COMPARISON OF FOUR ALGORITHMS

Fig.11 demonstrates comparison of bandwidth jitter indexes of four algorithms based on spectrum aggregation. Performance of GPF-Extension is the best. Under this circumstance, GPF-Extension algorithm provides full coverage of signal for SUs to aggregate band resources unrestrictedly. So its bandwidth jitter index is the lowest. Under GPF condition, the jitter index of GPF algorithm change tremendously as positions vary. From the simulation of GPF, first ten SUs are located in the area of full coverage of signal so the first part of jitter index is the lowest. And the middle ten SUs are located at the boundary of shadow and area of full coverage of signal. Their band resources available for aggregation reduce so that this part of bandwidth jitter index rises. The last ten SUs are located at the furthest places of shadow. Their resources continue the downward trend and aggregation for SUs are affected. Consequently the bandwidth jitter index of this part is the highest of all. GPPF and PPF-Shadow are

the same situation. At the cost of bandwidth jitter index, GPPF promotes fairness among SUs especially the SUs in shadow. Therefore each SU will own nearly the same bandwidth and jitter index.

Conclusions

A global positional proportional fairness (GPPF) scheduling algorithm is proposed in this paper. The purpose of GPPF is to solve the problem of unfairness resources scheduling based on spectrum aggregation. This novel scheduling algorithm brings in weighted factor β to improve the priority of SUs whose band resources for aggregation are restricted by disadvantage positions. At the cost of bandwidth jitter index, fairness scheduling among SUs are established for spectrum aggregation. Finally the simulation results show that bandwidths of SUs are nearly the same if GPPF is applied. And GPPF is fairer than the traditional scheduling algorithm GPF and PPF-Shadow in the area of incompletely coverage of signal.

ACKNOWLEDGMENT

The heading of the Acknowledgment section and the References section must not be numbered.

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Cong Yin received the B.S. and the M.S. degrees from Harbin University of Science and Technology, Harbin, China, in 2008 and 2011, respectively. He is currently working toward the Ph.D. degree with the School of Electronics and Information Engineering, Harbin Institute of Technology. His research interests include spectrum aggregation and spectrum handoff for cognitive radio networks, as well as the fairness scheduling in wireless communication systems.

Xuezhi Tan received the B.S., M.S., and Ph.D. degrees from Harbin Institute of Technology, Harbin, China, in 1982, 1986, and 2005, respectively. From October 1988 to March 1990, he was a Visiting Scholar with Kyoto University, Kyoto, Japan. He is currently a Professor with the School of Electronics and Information Engineering, Harbin Institute of Technology. He is a Senior Member of the Chinese Institute of Electronics and the Chinese Institute of Communication. He had published more than 70 papers in international journals. His research interests include wireless communications, digital trunking communication, and cognitive radio.